AD-A016 222

ILLIAC IV APPLICATIONS RESEARCH

Illinois University at Urbana-Champaign

Prepared for:

Army Research Office - Durham
Advanced Research Projects Agency

31 December 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CAC Document No. 177	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Semiannual Technical Report of the Center for Advanced Computation July 1, 1974 - December 31, 1974		5. TYPE OF REPORT & PERIOD COVERED Research Report 6. PERFORMING ORG. REPORT NUMBER CAC-177
7. AUTHOR(s) Center for Advanced Computation		8. CONTRACT OR GRANT NUMBER(s) DAHC04-72-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS Center for Advanced Computation University of Illinois at Urbana-Champaign Urbana, Illinois 61801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order No. 1899
11. CONTROLLING OFFICE NAME AND ADDRESS Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia		12. REPORT DATE February 1, 1975 13. NUMBER OF PAGES 48
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) U. S. Army Research Office Box CM, Duke Station Durham, North Carolina 27706		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release; distribution unlimited.

18. SUPPLEMENTARY NOTES

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Applied mathematics
Pictorial pattern information processing
Distributed computer systems
Network terminal systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See the Report Summary on page 1 within the report itself.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CAC DOCUMENT NO. 177

ILLIAC IV APPLICATIONS RESEARCH:

FINAL SEMI-ANNUAL TECHNICAL REPORT

July 1, 1974 to December 31, 1974

Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

Form Approved
Budget Bureau No. 22-R0293

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U. S. Government. This work was supported in part by the Advanced Research Projects Agency of the Department of Defense and was monitored by the U. S. Army Research Office under Contract: No. DAHC04-72-C-0001:

Principal Investigator: D. L. Slotnick (217) 333-6726;
Contractor: Board of Trustees, University of Illinois;
Program Code Number 2P10;
Amount of Contract: $4,000,646;
Sponsored by: Advanced Research Projects Agency,
ARPA Order No. 1899;
Dates: 12 July 1971 - 31 December 1974;
Title: "ILLIAC IV Applications Research."

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CENTER FOR ADVANCED COMPUTATION REPORT SUMMARY

This is a final semi-annual report on ARPA Contract DAHC04-72-C-0001, entitled, "ILLIAC IV Appications Research at the Center for Advanced Computation, University of Illinois at Urbana-Champaign."

During this period work was performed in the following areas:

1. Development of numerical techniques suitable for parallel processing.
2. ILLIAC IV multispectral image processing
3. Research in distributed computational systems of heterogeneous computers.
4. Research and development of network access

The major thrust of the numerical techniques work was in the area of computational linear algebra. Several parallel algorithms developed during this time period are described.

The Pattern Information Processing Group of CAC has explored the development of ILLIAC IV-ARPA Network multispectral image analysis system for digital interpretation of large quantities multispectral reconnaissance imagery, in collaboration with the Laboratory for Application of Remote Sensing (LARS) of Purdue University. The complete system has been designed and implemented to take full advantage of: The ILLIAC IV, the UNICON Data Computer, timesharing PDP-TENEX processors, the ARPA Network, and CAC's local PDP-11 computational facilities.

The Distributed Systems Group, formed in 1973, has conducted research in distributed computation systems composed of heterogeneous computer systems. Results are described in the use of PL/1 as a compatible language for implementing distributed systems, in process to process protocols; and in the economics of distributed computing.

The Network Access Systems Group, formed in 1973, evolved from support activities for the initial stages of this contract. The final efforts in the Mark II, ANTS Networks System and the PEESPOL compiler are described.

I. APPLIED MATHEMATHICS GROUP

A. Goals and Objectives

The main objective of the Applied Mathematics Group was the development of algorithms that are most suitable for parallel computers (namely the ILLIAC IV) in the following areas:

(i) Computational Methods in Linear Algebra

(ii) Linear Programming

(iii) Partial Differential Equations

(iv) Time Series Analysis

(v) Graph Algorithms

(vi) Approximation

Our major thrust however, was item (i).

B. Major Accomplishments

All the algorithms developed in the above areas have been debugged on the ILLIAC IV simulator running on the Burroughs B6700 computer at the University of California at San Diego.

(Accessed through the ARPAnet). Some of the algorithms are written in ASK, the majority, however, are written in ALGOL. Recently we have run successfully several algorithms on the ILLIAC IV itself (Fast Fourier Transforms, Eigenvalue routines, and our linear programming package).

The timing comparisons we obtained on the ILLIAC IV were not as good as those on the simulator. We believe that this is due to the temporary absence of some of the design features from the machine configuration.

C. Computational Linear Algebra

In the area of Computational Linear Algebra we have developed the following parallel algorithms:

(a) Solution of Systems of Linear Equations: Dense

1. Gaussian Elimination for solving a system of linear equations (non-core-contained), [1].

2. Householder's triangularization of a core-contained (320), [2].

3. Symmetric decomposition of positive - definite band matrices, [3].

(b) Eigenvalue Problem:

1. A parallel Jacobi method for finding the eigenvalues of a real symmetric matrix [4, 5 and 6].

2. A parallel algorithm for reducing a real matrix to the upper-Hessenberg form using orthogonal transformations, [7, 8].

3. The QR - algorithm for finding the eigenvalues of an upper-Hessenberg matrix, [9].

4. A Jacobi-like algorithm for finding the eigenvalues and vectors of a real nonsymmetric matrix, [4 and 6].

5. A modification of the bisection method for finding few or all of the eigenvalues of a symmetric tridiagonal matrix, [10].

6. The inverse iteration method for finding few or all of the eigenvectors of a symmetric tridiagonal matrix, [10].

7. A generalization of the simultaneous iteration method for finding the eigervalues and vectors in any given interval of a sparse symmetric matrix, [11].

D. Linear Programming

In the area of linear programming, the program implementing the revised simplex algorithm was largely written; however, it was not debugged with large data bases. This was mainly due to lack of complete documentation of the ILLIAC IV I/O. Since this I/O dependence proved to be a stumbling block in the early months of the ILLIAC IV availability, we decided to consider a new

algorithm [12, 13] due to Gill, Murray and Saunders (see also [14]). It was this new algorithm, for core-contained problems, that was debugged and tested on the ILLIAC IV. Good results have been obtained, i.e. solutions are the same as those obtained by MPS/360.

E. Partial Differential Equations

In the area of partial differential equations an extensive study of iterative and direct methods for solving the Poisson equation on the ILLIAC IV was completed. Several algorithms were modified and implemented, [15];

1. Successive Overrelaxation method (MSLOR, MSOR)
2. Alternating-Direction Implicit method (ADI)
3. Modified Hockney's method (MFACR)

Also a parallel modification of the Block-Jacobi iterative method for solving elliptic partial differential equations has been implemented on the ILLIAC IV [16].

A study of the identification of linear and nonlinear partial differential equations given noise contaminated observation of their solutions (state vectors) was undertaken and several algorithms were developed that are suitable for parallel computing [17, 18].

B. Time-Series Analysis

The main contribution in the area of time-series analysis is a Fast Fourier Transform, (one dimensional), subroutine that has been extensively tested and used on the ILLIAC IV. Several graph algorithms have also been implemented:

1. A modification of Warshall's algorithm for detecting whether a given matrix is irreducible, was demonstrated to be 29,000 times faster than its sequential counterpart on the B6700 for sizes less than 2,000 [19].

2. An algorithm for clique detection [20].

C. Approximation of Functions

Finally in the area of approximation of functions, methods for the simultaneous uniform fitting of sets of curves with certain parameters in common have been developed using linear programming [21].

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II. PICTORIAL PATTERN INFORMATION PROCESSING RESEARCH

A. Introduction

In support of the earth resources monitoring objectives of the ERTS/EROS programs of NASA and USGS, and in support of the ILLIAC IV application programs of NASA and ARPA at Ames Research Center, the Pattern Information Processing Group of CAC has explored the development of an ILLIAC IV-ARPA Network multispectral image analysis system for digital interpretation of large quantities of multispectral reconnaissance imagery. This work was undertaken with the collaborative support of the Laboratory for Applications of Remote Sensing (LARS) of Purdue University. Supplementary support for these efforts was received from the Statistical Reporting Service (SRS) of USDA.

The complete system was designed and implemented to exploit the full capabilities of:

(1) The ILLIAC IV for image processing calculations;

(2) The UNICON Data Computer of the ILLIAC IV Complex for storage and retrieval of numerous multispectral image files;

(3) The time-sharing PDP-TENEX processors of the ILLIAC IV Complex for small-scale interactive image analysis;

(4) The ARPA Network for decentralized user access to the system;

(5) The IBM 360/91 at UCLA for large-scale image processing and geographic registration procedures; and

(6) CAC's PDP-11 computational facilities for in-house image processing and display research.

B. ILLIAC IV Image Interpretation Algorithms

Following the LARS methodology of multispectral image interpretation, parallel algorithms were developed for both cluster analysis and statistical classification of multispectral image data. Both ASK and GLYPNIR implementations of these two algorithms are now operational on the ILLIAC IV and used routinely within CAC image processing research.

Experience with the ASK versions of these two algorithms during the last year indicates that the ILLIAC IV could be as much as two orders of magnitude more cost-effective than either the DEC PDP-TENEX or IBM 360/67 for interpretation of multispectral imagery using statisticl classification techniques. Algorithms developed in GLYPNIR, while easily programmed and modified within algorithm development research activities, tend to execute abot six times slower than corresponding ASK algorithms. Also, the availability of 32-bit arithmetic within ASK contributes substantially to the

attractiveness of ASK for image processing applications, despite the additional programming difficulties.

ILLIAC IV block-correlation algorithms are also now operational for multiple image registration and overlay procedures. These algorithms were coded only in GLYPNIR.

C. Image Processing Data Management Systems

ILLIAC IV image processing systems now operational employ PDP-TENEX data management subsystems resident on ARPA Network PDP-TENEX computers at I-4/Ames and BBN. The PDP-TENEX data management systems at BBN allow interactive tape retrieval of specific multispectral image files and automatic transfer of these files via the ARPA Network to NASA/Ames for ILLIAC IV processing. The availability of tape units on the ILLIAC IV TENEX for general image process applications would greatly enhance the convenience of the ILLIAC IV Complex for image processing research. When available to users, the UNICON Data Computer should provide data management services of the scale required for operational ILLIAC IV image processing applications.

D. Interactive ARPA Network Image Processing

Considerable research was conducted at CAC during the last two years to assess the potentials of the ARPA Network as a means toward decentralization of ILLIAC IV image processing capabilities, and to provide access to other image processing software systems being developed.

Concerned initially with the development of basic software for simulation of alternative multispectral data management and processing systems that might be implemented at NASA/Ames using the UNICON Data Computer and peripheral PDP-TENEX processors in conjunction with ILLIAC IV processing, CAC developed an interactive multispectral image analysis system that is now operational on a number of PDP-TENEX computers on the network.

Designed to be addressed through low-cost portable terminals, the system allows interactive selection of image analysis windows from multispectral image data tapes, terminal printer display of the image data within these windows, interpretation of this data using statistical pattern recognition techniques, and terminal printed-character display of interpretations. Such interactive data management and analysis capabilities greatly facilitate the delineation of image resolution elements corresponding to areas of ground truth

information. For the present, the nature of portable terminals and dial-up telephone data transmission rates restricts use of the system to small-scale multispectral image analyses. These systems are currently being used however by NASA, USGS/DI, and SRS/USDA.

F. Other Image Processing Research Activities

Access to the ILLIAC IV and numerous other computational facilities of the ARPA Network allowed CAC to develop considerable experimental software for graphical display of multispectral image data. Using remote processing and terminal output devices at CAC, software was developed for plotter and line printer display of ERTS satellite imagery geometrically corrected to overlay USGS maps at specific scales and map projections. A modest research effort involved interactive image processing using the IMLAC and Computek CRT devices at CAC. Additionally, research was conducted toward the development of more appropriate numerical measures of pattern information correlation of the type required by template-matching pattern recognition methodologies and block-correlation image registration techniques. This research now points toward quite general mathematical models of pattern information processing.

III. DISTRIBUTED SYSTEMS

A. Introduction

The Distributed Systems Group (DSG) was formed in 1973 to conduct research in distributed computation systems composed of heterogeneous computer systems. DSG has investigated the use of PL/1 as a compatible language for implementing distributed systems; it has investigated process-to-process protocols; and and it has investigated the economics of distributed computing.

B. PL/1

The flexibility and power of PL/1, coupled with its wide availability, make it an attractive language for use in a heterogeneous environment. The PL/1 compatibility study completed in December, 1973 indicates that it would be reasonable to use PL/1 as a compatible language for the implementation of distributed systems.

C. Network Protocols

The study of resilient process-to-process protocols was completed in June, 1974. Two major conclusions arose from this study. The first is that it is feasible (and for some

applications desirable) to develop a resilient multi-level protocol to support a network utility. The second conclusion is that attempts to implement such a resilient process-level protocol would be fruitless without first re-designing all lower-level protocols so they too are either resilient or so that low-level failures can be detected and the protocol reset to an appropriate state for higher level recovery.

D. Network Economics

A series of benchmarks designed to quantify the cost effectiveness of various network hosts on a full cost-recovery basis was completed. The benchmarks tested the capability of each host in the areas of number crunching, bit and character string handling, file manipulation, and console management. The results of these benchmarks indicate that distributed systems implemented on dissimilar computers can have higher performace, higher reliability, and lower cost than would be possible on a single computation facility.

IV Network Access Systems

A. INTRODUCTION

The Network Access Systems Group, formally established in the fall of 1973, evolved from support activities initiated at the beginning of this cntract. The Network Access Systems Group staff were associated with the following contract activities:

1. ILLIAC IV documentation, user education and consultation.
2. Study of the applicability of ILLIAC IV in atmospheric dynamic calculations in conjunction with NSF support.
3. Cooperative development with the University of California at San Diego of a Network Control Program for the B6700.
4. Participation in ARPA Network protocol development, particularly in graphics.
5. Applications support in the area of graphics for the University of Illinois' Laboratory for Atmospheric Research.
6. Development of a hardware interface between the PDP-11 and the IMP.
7. Development of the ARPA Network Terminal System (ANTS, Mark I), a high level language compiler for its development (PEESPOL), and support of ANTS for a number of facilities on the ARPA Network, i.e., National Bureau of Standards, Lawrence Livermore Laboratories, University of California at Los Angeles, and the Army Material Command.

8. Development of a software interface for the University of Illinois' PLATO system to the ARPA Network through ANTS, Mark I.

9. Development of ANTS, Mark II and its support at a number of ARPA contractor facilities.

These activities have been reported in previous semi-annual reports. The following reports on the groups' activities in the final six month phase of the ARPA contract.

B. ANTS Mark II

Following the completion of check-out for levels 0 and 1 on the ANTS Mark II system attempts were made to compile a complete system including the Network Control Program, (NCP), Telnet, and the terminal handler. The resultant complete system was found to be too large for the 28k of addressable core on the PDP 11/50. After repeated efforts to reduce the size of the system by selective pruning and elimination of unneccessary features, a working version of ANTS Mark II was obtained. This system supported the following features in the terminal handler:

Line and character editing;
Simulated backspace and line feed;
Multiple network connections from a terminal;
Character at a time or line at a time mode;
Local or remote echo.

However, the reliability of the system suffered greatly as a result of core constraints when the number of logged-in terminals exceeded four.

While efforts were underway to solve the memory constraints and reliability problems, handlers were written for the LV-11 printer, the DH-11 multiplexor and DECtapes. A system was

completed for the UCLA-Network Measurement Center using the DH-11 driver, and saw limited service. Also a system was completed using the Very Distant Host interface and the RK05 disk system at Lincoln Laboratories.

In a related activity, a system was compiled for the Army Material Command, which provides a limited RJE capability from the Ballistics Research Laboratory at Aberdeen, Maryland to the Mobility Research and Development Center at Fort Belvoir, via the ARPAnet. Also TELNET access is available to the network from BRL.

A simplified file system was devised which would use a naming convention compatible with DEC's disk operating system. A major portion of the code for the file system was completed in the waning months of the contract, but was not completed and checked out. Similarly, designs for FTP, NETRJE, and magnetic tapes were completed only through the initial stages.

An effort was undertaken to provide the PEESPOL compiler with the capability of binding separately compiled modules together to form a complete code file. This version of the compiler was successful to the point that the predecessor, Mark I ANTS, was compiled and working with this compiler. However, the nature of the ANTS Mark II system has imposed several problems for this version of the compiler. After considerable effort to

compile a version of Mark II with the new compiler it became clear that the benefits to be derived from this effort would not outweigh its cost. The files were archived and this portion of the PEESPOL effort was terminated.

C. IMP Interface

During the months of June and July, the reference manual for the PDP-11 to IMP Interface was revised. A set of diagnostic programs got a thorough break-in as a result of a successful attempt to identify and correct a hardware problem with our IMP Interface. A manual describing the nature and operation of these diagnostic procedures was produced.

D. Conclusions and Implications for the Future

Over the span of some three and one-half years under the ILLIAC IV Applications contract, the group which came to be known as the Network Terminal Systems Group, has been working on the subtask of providing a reliable and economic means of accessing the ARPAnet. These efforts, combined with interaction amongst various similar working groups at other network nodes, have lead to the following conclusions:

1. The PDP-11 to IMP interface which was designed and constructed as a part of this subtask, has served it's purpose well. Several of these units are still in daily operation, including two units at Illinois and units at BRL, Ft. Belvoir, UCLA, Utah, New York University, and NASA Ames. The units operate well, in spite of the fact that they were designed with th proven technology of five years ago. Today's technology makes it possible to design and construct the same functional unit at a lower cost. The groundswell of network support for the PDP-11 as a mini-host has even made it cost-effective for the Digital Equipment Corporation to include a PDP-11 to IMP interface in their line of peripherals.

2. The ARPA Network Terminal System (ANTS Mark I) has been in use at the University of Illinois since September 1971. In spite of the conditions under which it was developed (a deadline to get on the net, no manufacturers software beyond paper tape software, repeated difficulties with the B6700 at that time, etc.) it has been a highly efficient and reliable means of access to the network for Telnet, CCNRJS, and limited magnetic tape and printer retrieval of files from the network. Network throughput statistics for June of 1975 show this system to handle more network traffic than any of the more recently developed PDP-11 systems. Perhaps because of its limited design goals, it supports more Telnet connections than any of the more recent PDP-11 systems, and supports features that are recently being added or asked for in the TIP (user login, password, accounting; local or remote echo; to name two).

3. The notion of a programming language used on one machine to produce code for another, such as the PEESPOL effort, is commonly accepted as the most effective way of producing code for PDP-11 network systems in the ARPAnet community. Although the language was intended primarily for operating systems code, and unfortunatel depended largely upon the machine structure of the Burroughs B6700, it did establish that a higher level language can be effectively used for the development of codes for a mini-computer, and its use can be geographically independent because of the access via the ARPAnet. The meta-programming capabilities of this compiler

represent a significant departure from traditional languages available for coding in a mini-computer.

4. The ANTS Mark II effort, was not highly successful as a completed and reliably functioning system. In retrospect, several things are apparent that perhaps should have been earlier, and it is a matter of conjecture as to which of them was most responsible for the failure of the system to meet its early promise.

For systems requiring only Telnet access, the simplest design is the most desirable. This is necessary in order to maximize throughput and is achieved at the expense of elaborate file handling, local user processes, and user aids such as command completion and in-line "help" functions. Generality in the operating system turned out to be prohibitively expensive in terms of core space and repeated handling of single characters. The goal of a generalized system in a 24k core-contained version was not attainable, and the system design was so pointed at the generalized system that it could not be conveniently reduced to a small special purpose (Telnet) high throughput system.

When the goal is a generalized system for a mini-computer such as the PDP-11 , it must be recognized that both disk-swapping and memory management (as well as plenty of memory) will be necessary. The compiler and the operating system must both be designed from the outset to expect and take advantage of these elements. A simple overlay technique as used in ANTS Mark II is no adequate substitute for a full swapping scheme.

It seems unwise, based on the experience with ANTS and recent experiences with similarly directed efforts, to expect a single system design to be expandable from a 24k single-purpose system to a 48k or larger generalized system which will support FTP, RJE, user files, editors, etc. Similarly, allowing an effort

directed at the former to simply grow by addition of personnel into the latter, has again proven to be unproductive.

What was lacking in the beginning was an acceptable time-sharing system for the PDP-11 class of mini-computer. The ANTS Mark II and the ELF system both seem to try to correct that lack by evolving a terminal handling system into a time-sharing system. On the other hand, the large systems on the ARPAnet were already time-sharing systems (Tenex is the most notable example) that have had the network capability added. Such a system is complemented by the network rather than existing for the network.

A recent addition to the expanding collection of available PDP-11 time-sharing systems is the Unix system developed at Bell Laboratories. This system is a stand-alone sharing time-sharing system in its own right and in its original design. Fortunately its organization, file structure, language, etc., make it a very viable system for local programming, as well as for connecting to the ARPAnet. The experience of working on NCP's for two ANTS systems and a Burroughs B6700 made it possible for still another NCP and Telnet to be added to Unix in an extremely short period of time. (Although this work was completed after the ARPA contract had expired, and not under ARPA funding, the results are available to all licensed Unix installations as a courtesy. The advantage to Unix in this instance was the same as the advantage to Tenex: the system already worked, memory management was an integral part, the file system was well

established, and the appropriate language was in existence at the outset of the network development work.

For network applications where local files and languages are needed and the network is a complement to the local facilities provided, Unix seems to be the most viable choice at the present time. It also has sufficient capability to be used in future development of PDP-11 based systems for special purposes on similar or smaller PDP-11's for graphics support, inter-machine connection, intelligent terminals, and other dedicated mini-computer applications.

ADMINISTRATION AND FISCAL STATUS

Expenditures for the period October 1, 1974 through December 31, 1974:

October	$ 80,479.46
November	61,161.27
December	14,406.60

Remaining Obligations: ($194,554.53)

Total Actual Expenditures through December 31, 1974: $4,044,682.53.

APPENDIX A: REPORTS AND PUBLICATIONS

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APPENDIX B: PARTICIPATING PERSONNEL

ACADEMIC STAFF

Peter A. Alsberg
David Beckles
Marion C. Bedell
Geneva G. Belford
Roger H. Bezdek
Wendell J. Bouknight
Clark W. Bullard
Joyce Chen
Paul Cichy
John Day
Edmund J. Dewan
Stewart Denenberg
Walter E. Donovan
Hugh Folk
Celso J. Frazao
Joseph A. Garber
James A. Gast
Marvin Graham
Gary R. Grossman
David M. Grothe
Bruce P. Hanna
Bruce M. Hannon
James H. Hansen
David C. Healy
Steven F. Holmgren
Dorothy J. Hopkin
Robert J. Husby
Renato Iturriaga
Sue-Ellen Jacobs
Karl F. Johnson
Karl C. Kelley
Delbert E. Knecht
Frank Knowles
Jean A. Langford
Terry J. Layman
Raymond J. Lermit
James Madden
Tom Mason
Lawrence McDaniel
John C. McMillan
Jaacov Meir
Tom Milke
Kenichi Miura
John R. Mullen
Killian Noh
Masako Ogura
Martin Ozga
Paul L. Petronelli
George B. Purdy
S. Rajan
Robert Ray
Richard Roistacher
Ahmed Sameh
Stewart A. Schuster
Fred Segovich
Michael S. Sher
Daniel L. Slotnick
Janet H. Spoonamore
Jay Sullivan
John D. Thomas
George A. Westlund
Linda K. Zapf

GRADUATE STUDENTS

Tom Asbury
Mike Babcock
Maynard Brandon
Timothy J. Berkesch
Deborah S. Brown
Steve Bunch
Gilbert Cardenas
Chang-Chung Chang
Charles Christian
William Croisant
Robert Dauffenbach
Patrick Donnelly
Keith Erickson
Deborah Forman
A. L. Gaffney
Wallace Gatewood
Barry Getzel
Enrique Grapa
Ronald B. Halcrow
Brian A. Hansche
Kenneth R. Howse
Hui-Ming Huang
Francisco Izquiendo
Morris Kleiner
Surender Kumar
Shea-Fen Kuo
Glenn LaVine
Francoise Markus
Craig Mills
Kenichi Miura
Mathew J. Morey
Killian Noh
Gary J. Pace
Richard Pestien
Carol Ann Schaller
Richard Neal Schubert
John T. Soma
James E. Stevens
M. Talaat
Paul Wang
David Wilcox
Edward Willauer
Emilye Williams

APPENDIX C: ADVANCED DEGREES EARNED UNDER PROJECT SPONSORSHIP

C. C. Chang	Masters in Computer Science
C. K. Chen	Ph.D in Computer Science
A. L. Gaffney	Masters in Computer Science
J. H. Ericksen	Ph.D in Computer Science
H. M. Huang	Masters in Computer Science
P. J. Lermit	Ph.D in Computer Science
K. Uno	Ph.D in Economics
S. A. Schuster	Ph.D in Computer Science
J. E. Stevens, Jr.	Ph.D in Computer Science
R. B. Wilhelmson	Ph.D in Computer Science